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GATE STATISTICS FOR THE GEOS-3 SATELLITE
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A Study of Possible Sea State Information in the Sample and Hold Gate Statistics for the GEOS-3 Satellite Altimeter

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NASA

National Aeronautics and
Space Administration

Wallops Flight Center

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A STUDY OF POSSIBLE SEA STATE INFORMATION IN THE SAMPLE AND HOLD GATE STATISTICS FOR THE GEOS-3 SATELLITE ALTIMETER

1.0 INTRODUCTION AND SUMMARY

The GEOS-3 satellite altimeter in the short Pulse Data Mode has a waveform sampling system composed of 16 sampling gates to provide information concerning the shape of the average impulse response of the ocean surface and the amplitude probability distribution of the echo energy.

The sample gate outputs are available at the PRF rate so that individual return pulse shapes can be reconstructed or so the amplitude probability density function at a particular time point within the return pulse can be constructed. A three dimensional plot of a typical frame of data is shown in Figure 1.

The purpose of the study described in this report is to examine the statistical variations in the sample gate outputs for possible sea state information. After extensive examination of a large number of statistical characteristics of the GEOS-3 altimeter waveforms it was found that the best sea ($H_{1/3}$) state predictor for $H_{1/3}$ in the range of 0 to 3 meters was the 75th percentile of sample and hold gate number 11.

2.0 INITIAL APPROACH

The first approach was to construct histograms of the data on a per frame basis for visual inspection. Examples of these are given in Figures 2 and 3 for a relatively calm sea and a sea state for which $H_{1/3} = 5$ meters. As can be seen from the superposition plot in Figure 1 the overall difference is rather subtle.

It is seen that the frequency function is not pure exponential or Gaussian but rather a skewed function. In order to study the differences further a fit of a lognormal density function given by

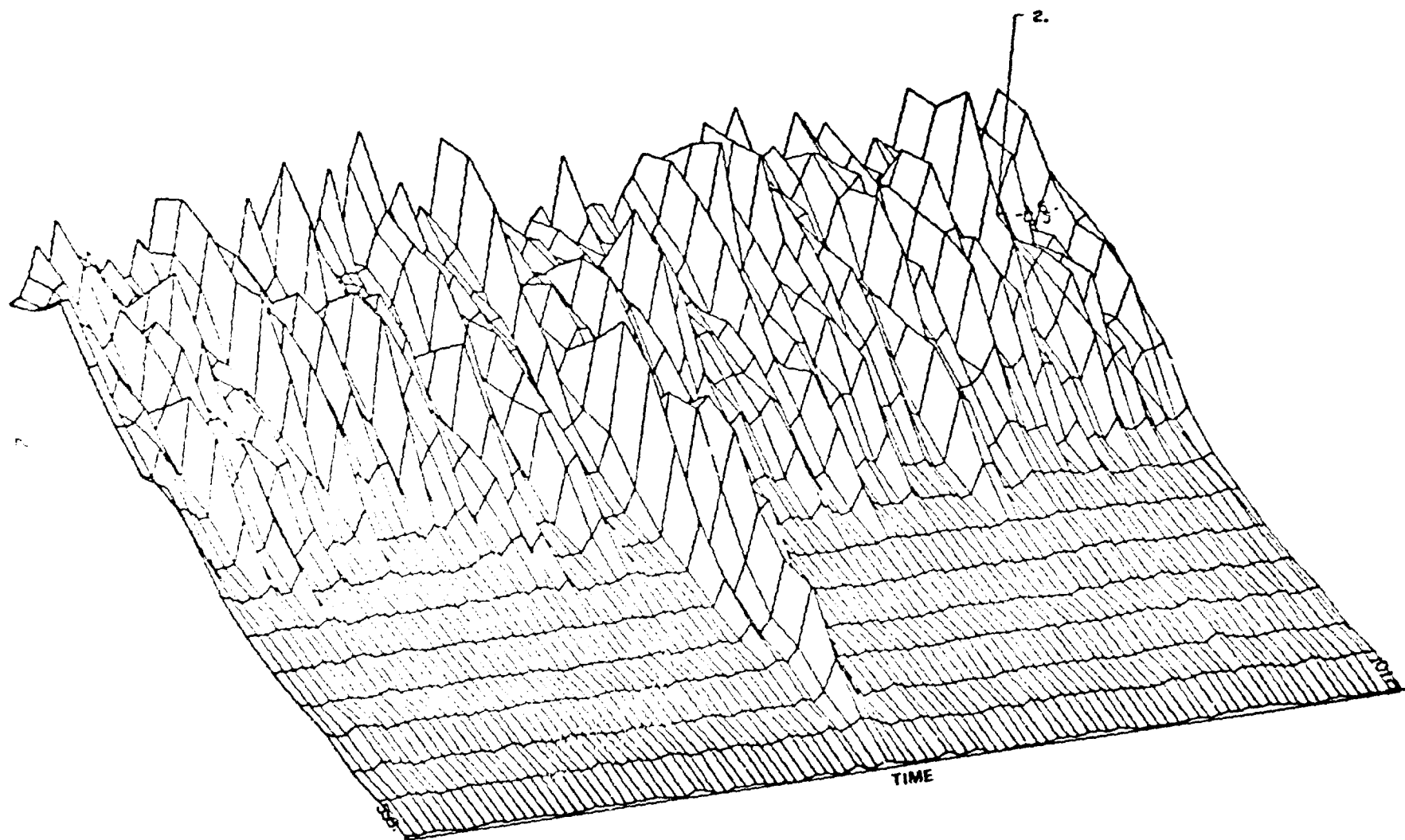


FIGURE 1. TYPICAL INSTANTANEOUS RETURN WAVEFORMS

$$f(x) = \frac{1}{x\sqrt{2\pi\beta}} e^{-\frac{1}{2\beta} (\ln x - \mu)^2} \quad x > 0,$$

was made. The parameters μ and β were estimated and examples of the fitted frequency function are shown in Figures 2, 3 and 4. While the fit looks good it does not serve the purpose of amplifying the sea state differences.

3.0 TOTAL WAVEFORM VARIATION ANALYSIS

Another approach to the correlation of waveform statistics with sea state was an analysis of the total waveform variation. For this approach each return waveform was treated as a sample random variable $x = (x_1, x_2, \dots, x_{16})$ and a variance covariance matrix Σ (16x16) was computed for each frame of data. The total variation in the waveform is then measured in terms of the trace of $\Sigma = \lambda_1 + \lambda_2 + \dots + \lambda_{16}$ where λ_i is a latent root of the variance covariance matrix. Also of interest is an examination of the largest and smallest latent roots. After an extensive examination of these quantities no significant correlation with sea state was found. From this analysis it was concluded that waveform second order statistics were not useful for sea state determination.

HISTOGRAM
S/H GATE 16 HIGH SEA STATE

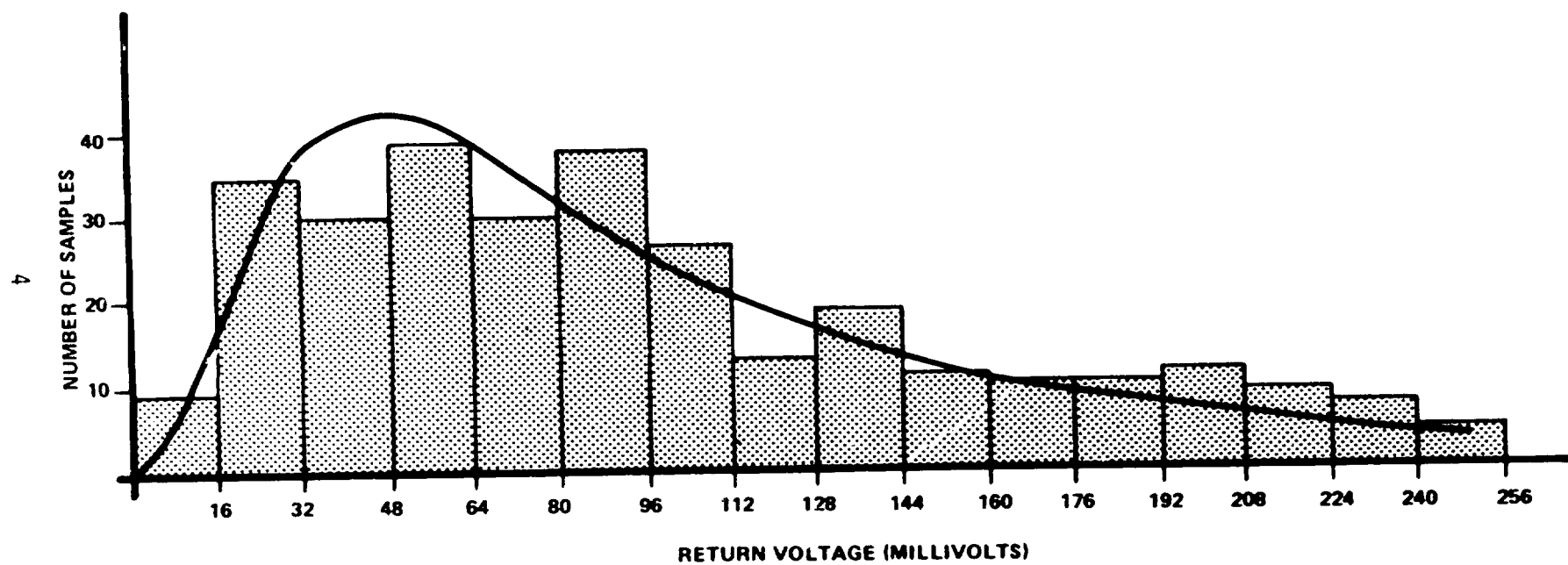


FIGURE 2. HISTOGRAM FOR GATE 16 HIGH SEA STATE, $H_{1/3} = 5$ METERS

HISTOGRAM
S/H GATE 16 LOW SEA STATE

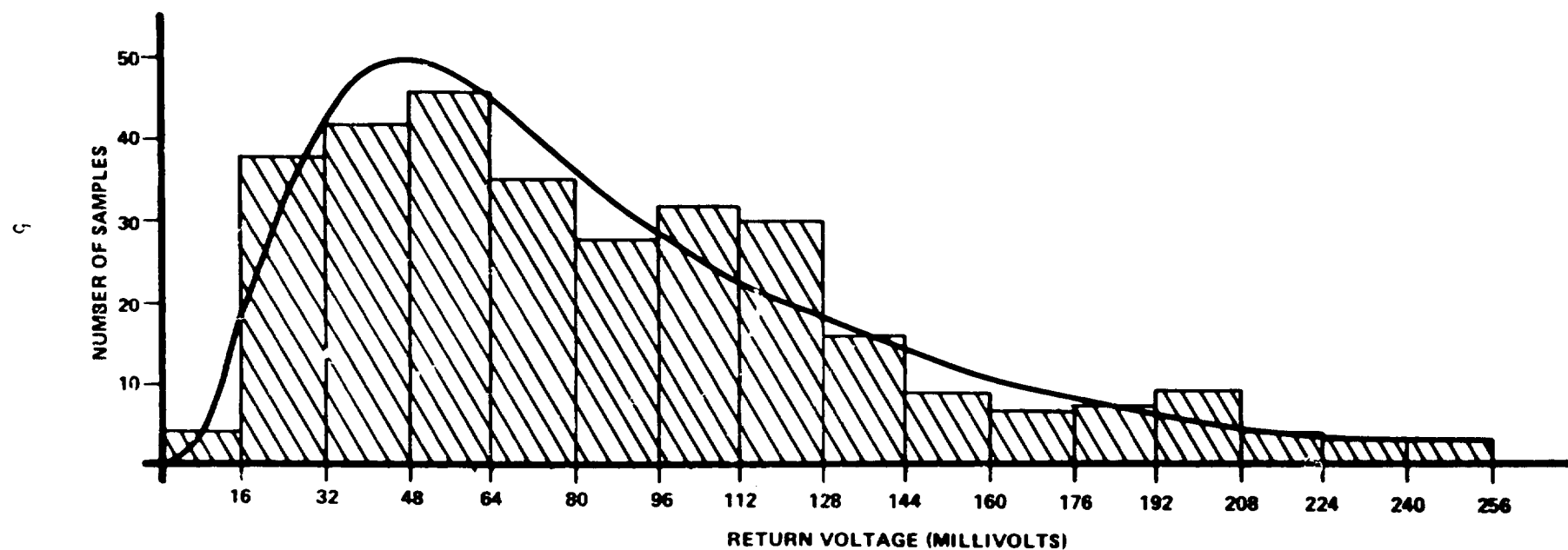


FIGURE 3. HISTOGRAM FOR GATE 16 LOW SEA STATE, $H_{1/3} = 0.5$ METERS

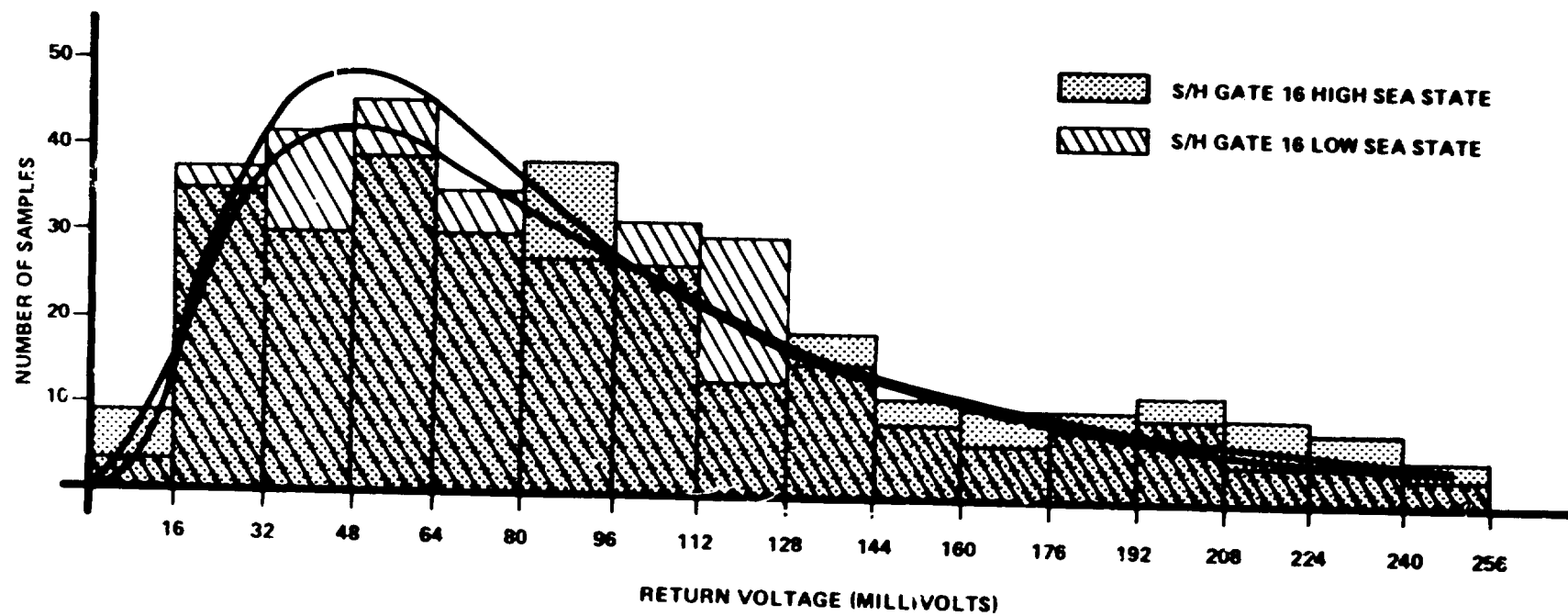


FIGURE 4. HISTOGRAMS FOR GATE 16, HIGH AND LOW SEA STATE

4.0 THIRD AND FOURTH MOMENT ANALYSIS

The next approach was to examine the skewness and kurtosis of the individual gates where skewness parameter is given by

$$\alpha_3 = \frac{\sum_{i=1}^n (x_i - \bar{x})^3}{\left[\sum_{i=1}^n (x_i - \bar{x})^2 \right]^{3/2}}$$

and kurtosis parameter is given by

$$\alpha_4 = \frac{\sum_{i=1}^n (x_i - \bar{x})^4}{\left[\sum_{i=1}^n (x_i - \bar{x})^2 \right]^2}$$

For a Gaussian density function $\alpha_3 = 0$ and $\alpha_4 = 3$ and for an exponential density function $\alpha_3 = 2$ and $\alpha_4 = 9$.

This analysis was based on an examination of the histograms of the return voltage in the individual gates. A typical example is shown in Table I for $H_{1/3} = 0$ and $H_{1/3} = 6$ meters.

Rev 4604 was chosen to investigate this effect since it contained data for a variety of sea states from 0 to 6 meters. Figure 5 is a plot of the seven frame moving average $H_{1/3}$ for Rev 4604. Figures 6 through 21 present a plot of the skewness and kurtosis coefficients for sample and hold gates 1 to 16. By visual inspection it can be seen that gates 2, 3, 4, 5 and 6 correlate reasonably well with the $H_{1/3}$ values but this is not true of gates 7 to 16.

REV 4604 FRAME 14

$$H_{1/3} = 6$$

GATE NUMBER						
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
						2
						0
						0
						0
						0
						0
						0
					1	1
					1	1
					0	1
					0	0
					1	4
					0	1
			2		1	3
			2	2	4	7
	3	1	1	3	15	17
3	9	11	6	4	25	23
7	26	24	27	12	83	143
87	87	86	85	22	188	111
223	195	198	197	277	1	6

8

FRAME 91

$$H_{1/3} = 0$$

	1	7	3		2	2
99	155	149	154	7	113	214
221	164	164	163	313	204	103

TABLE I. TABULATION OF TYPICAL HISTOGRAMS FOR HIGH AND LOW SEA STATES

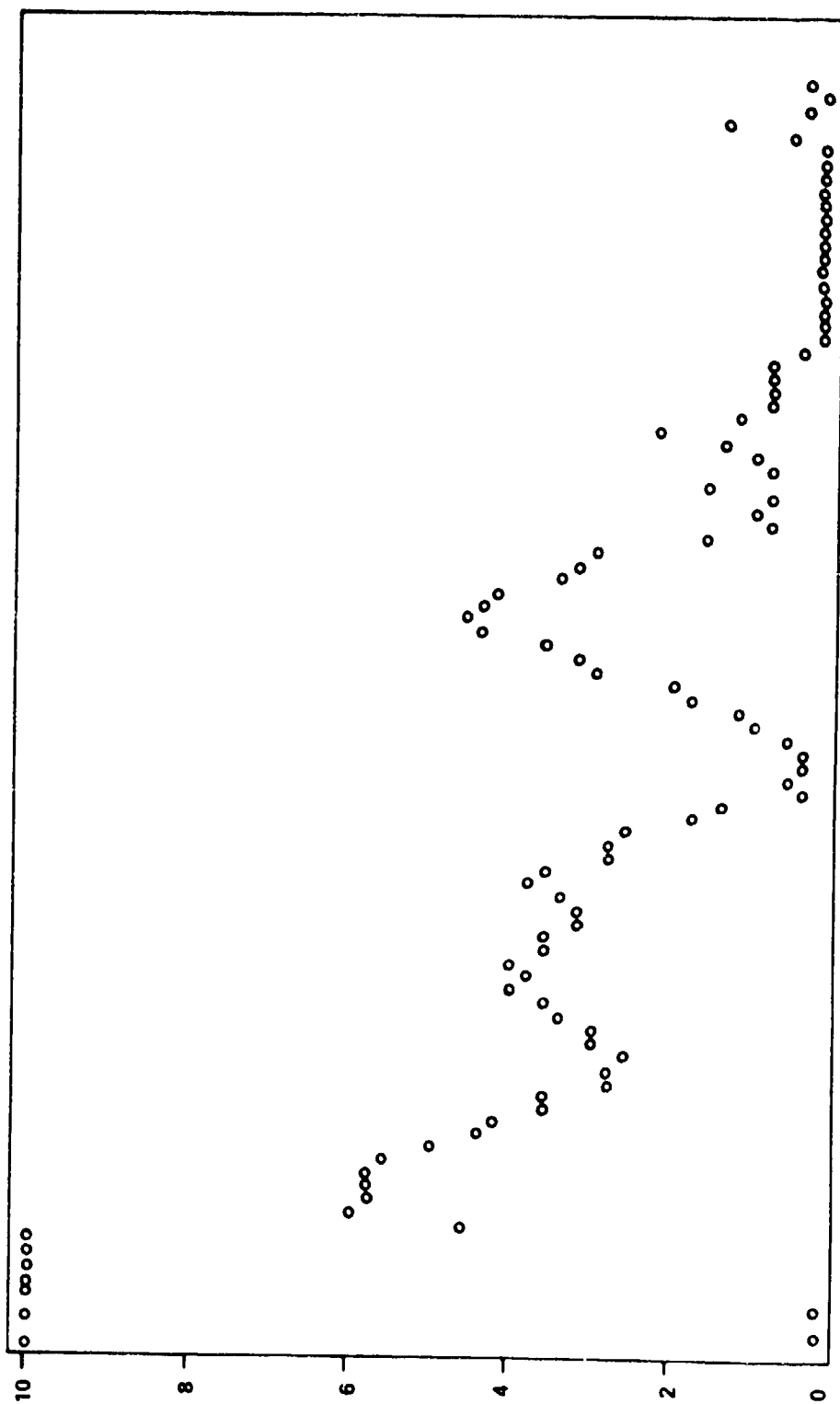


Figure 5. Seven Frame Moving Average $H_{1/3}$, Rev 4604

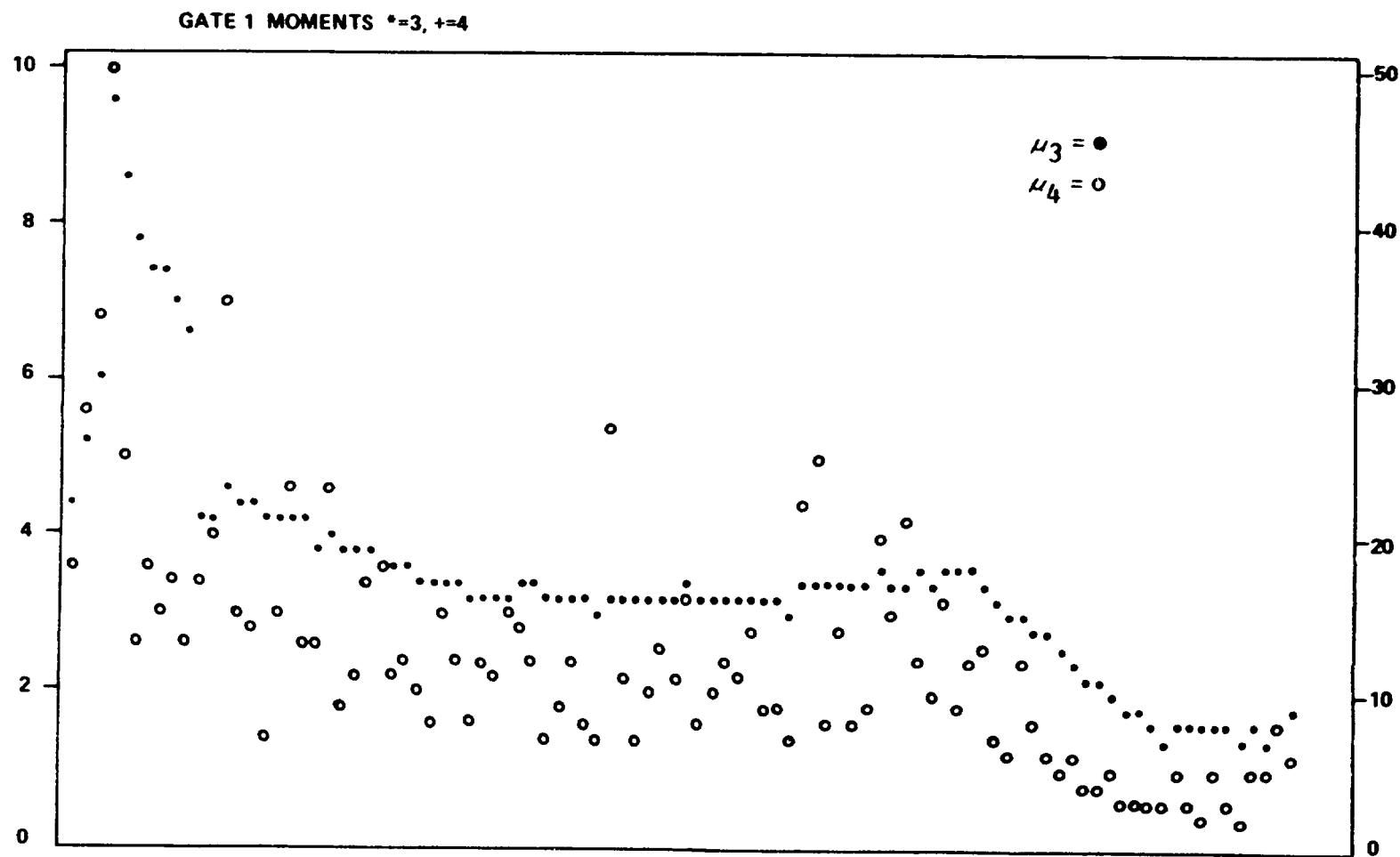


Figure 6. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 1

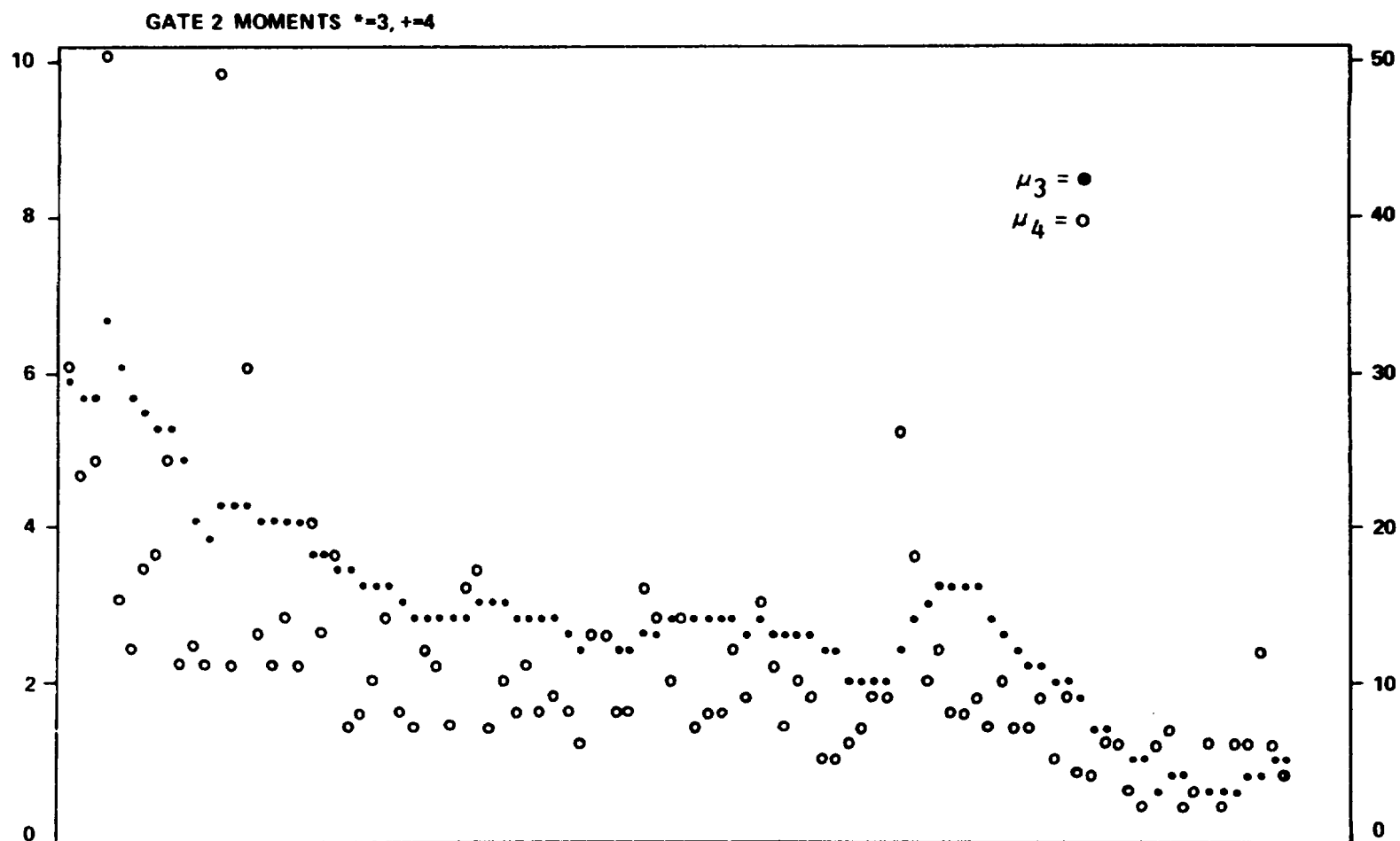


Figure 7. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 2

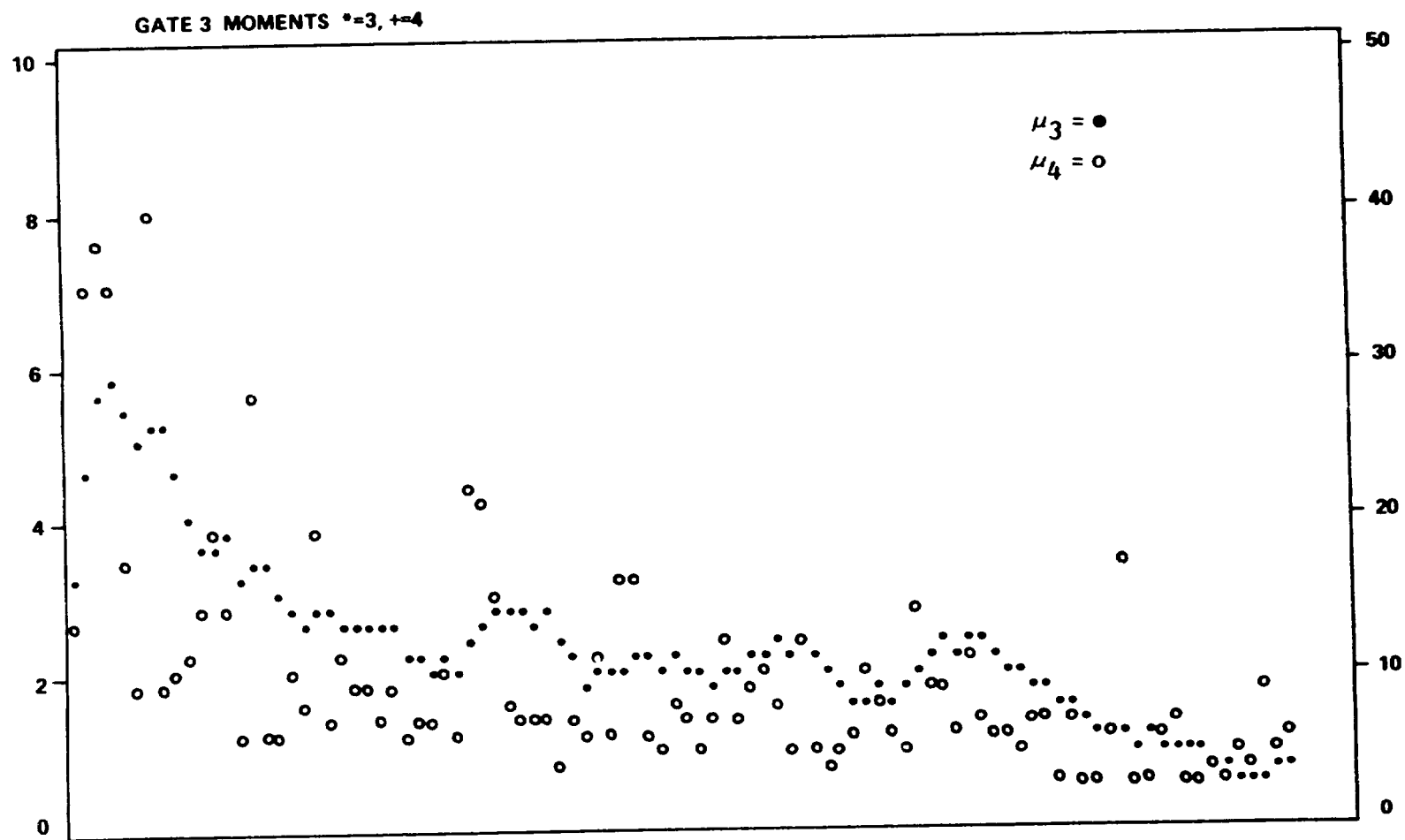


Figure 8. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 3

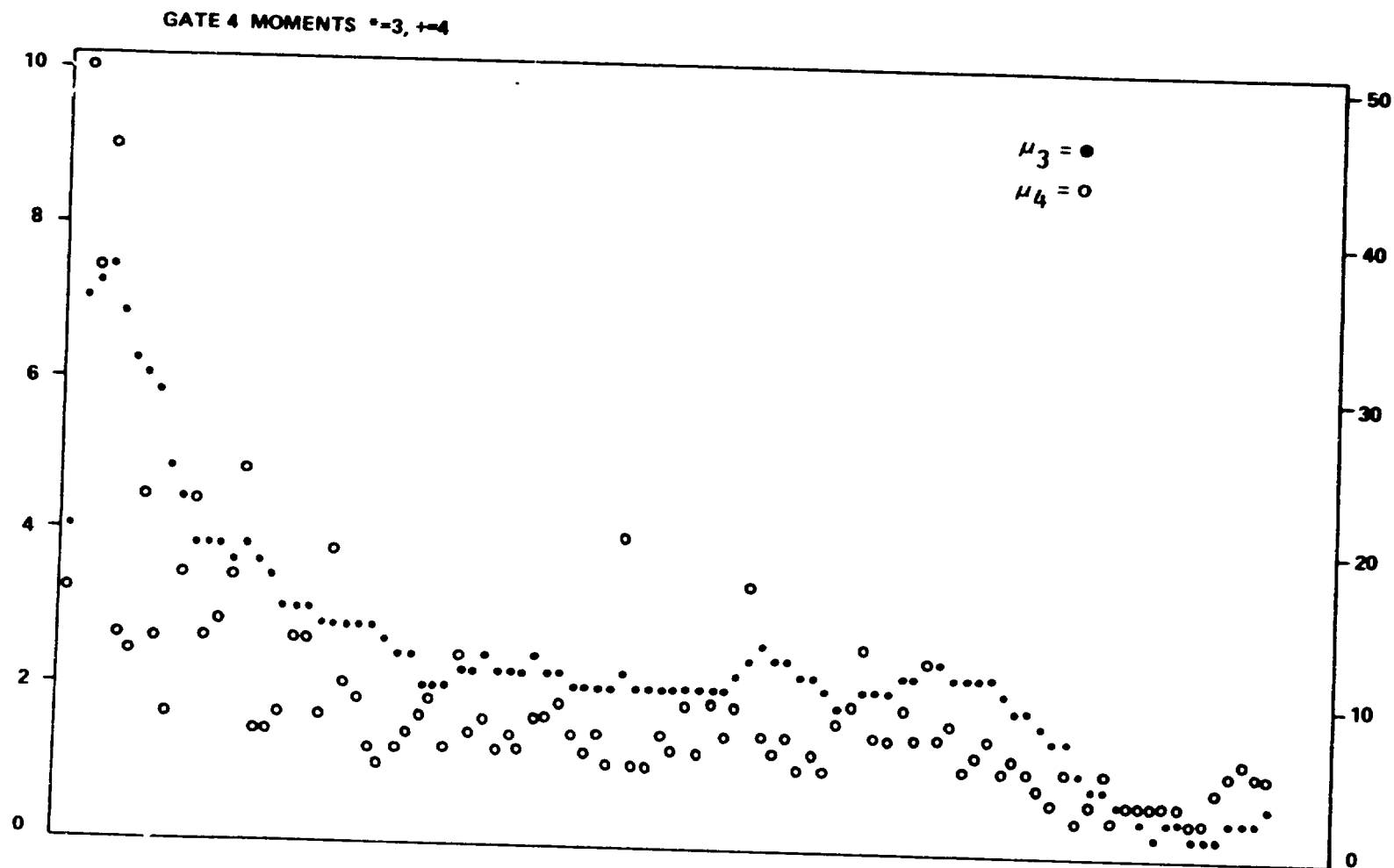


Figure 9. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 4

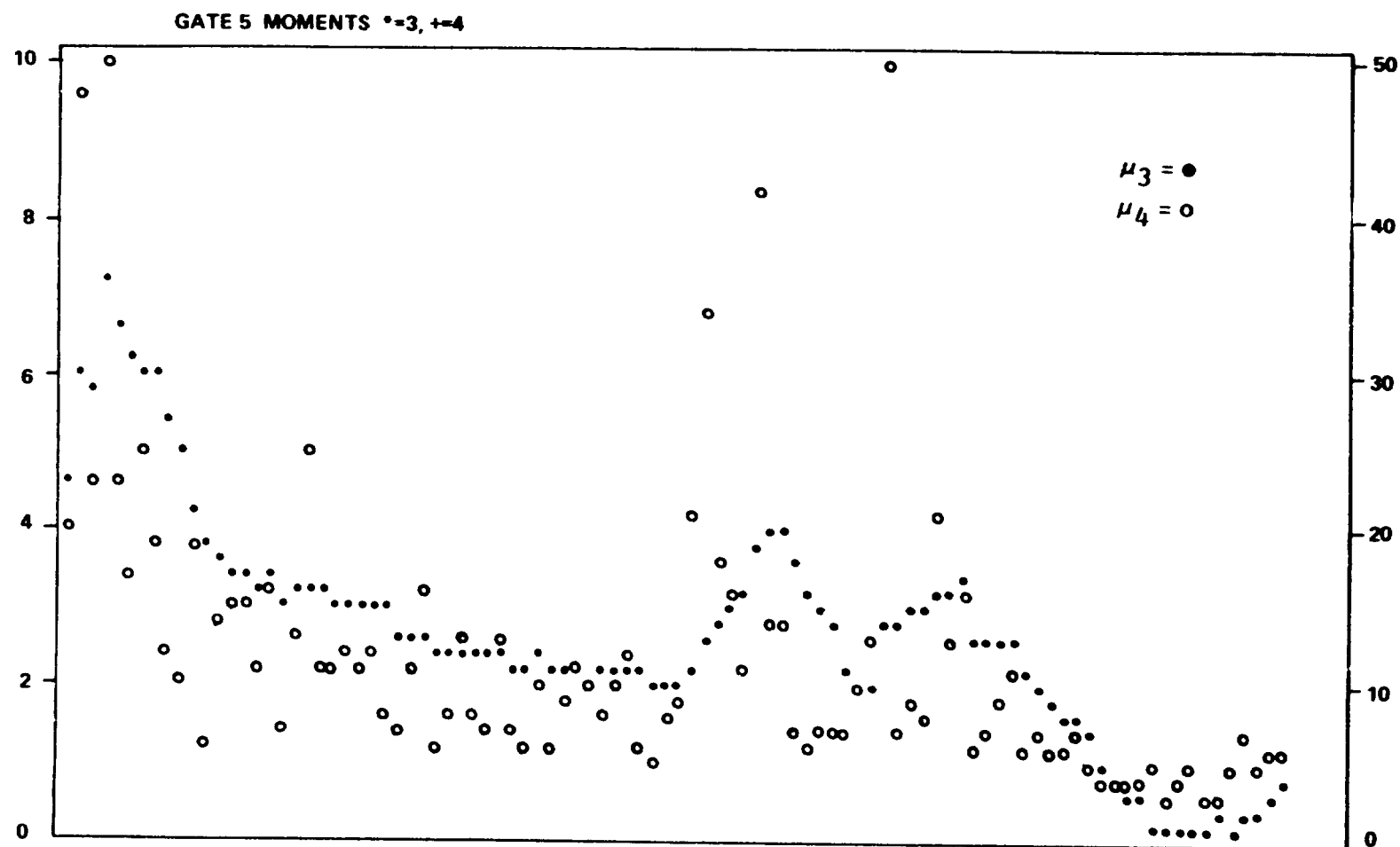


Figure 10. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 5

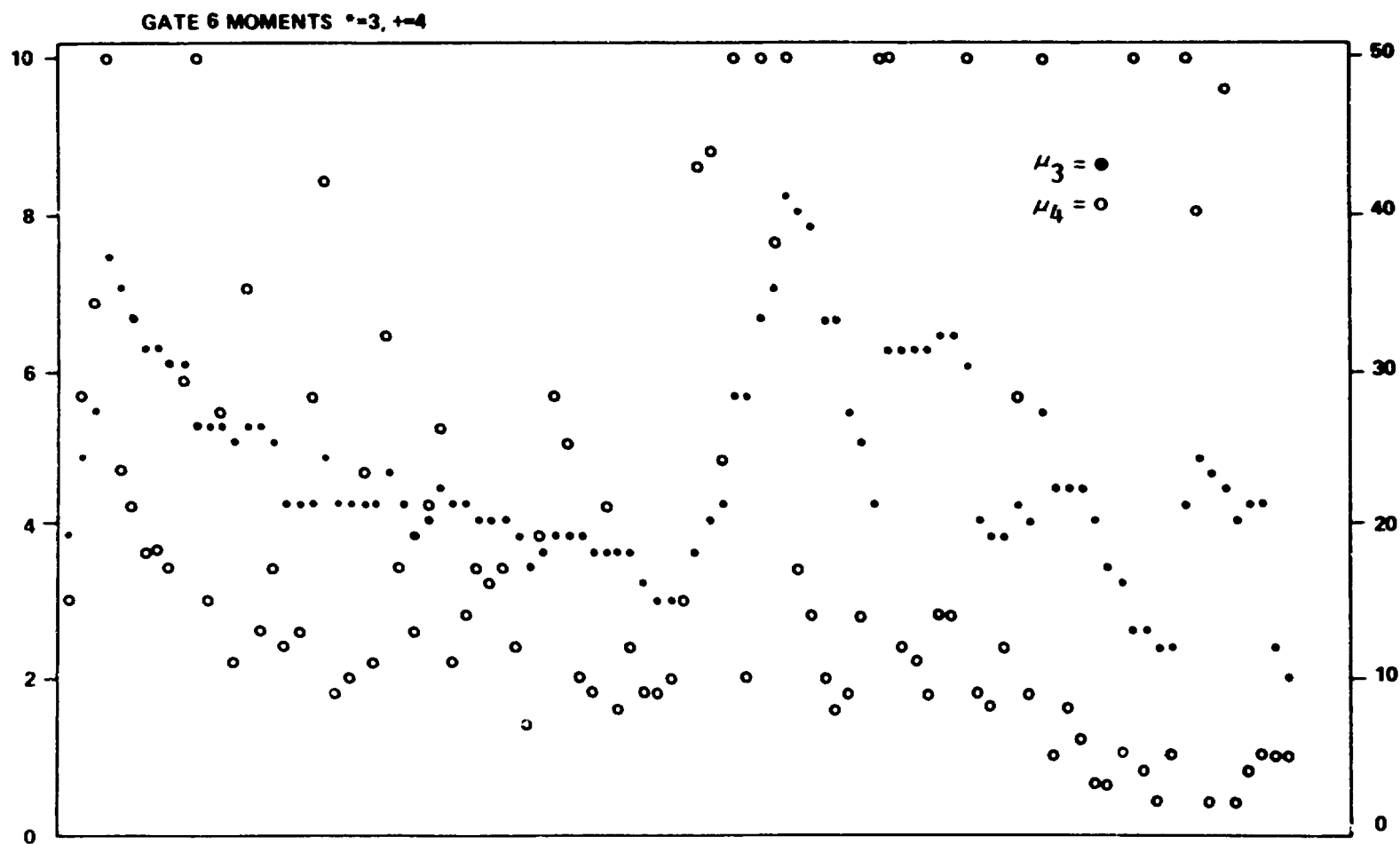


Figure 11. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 6

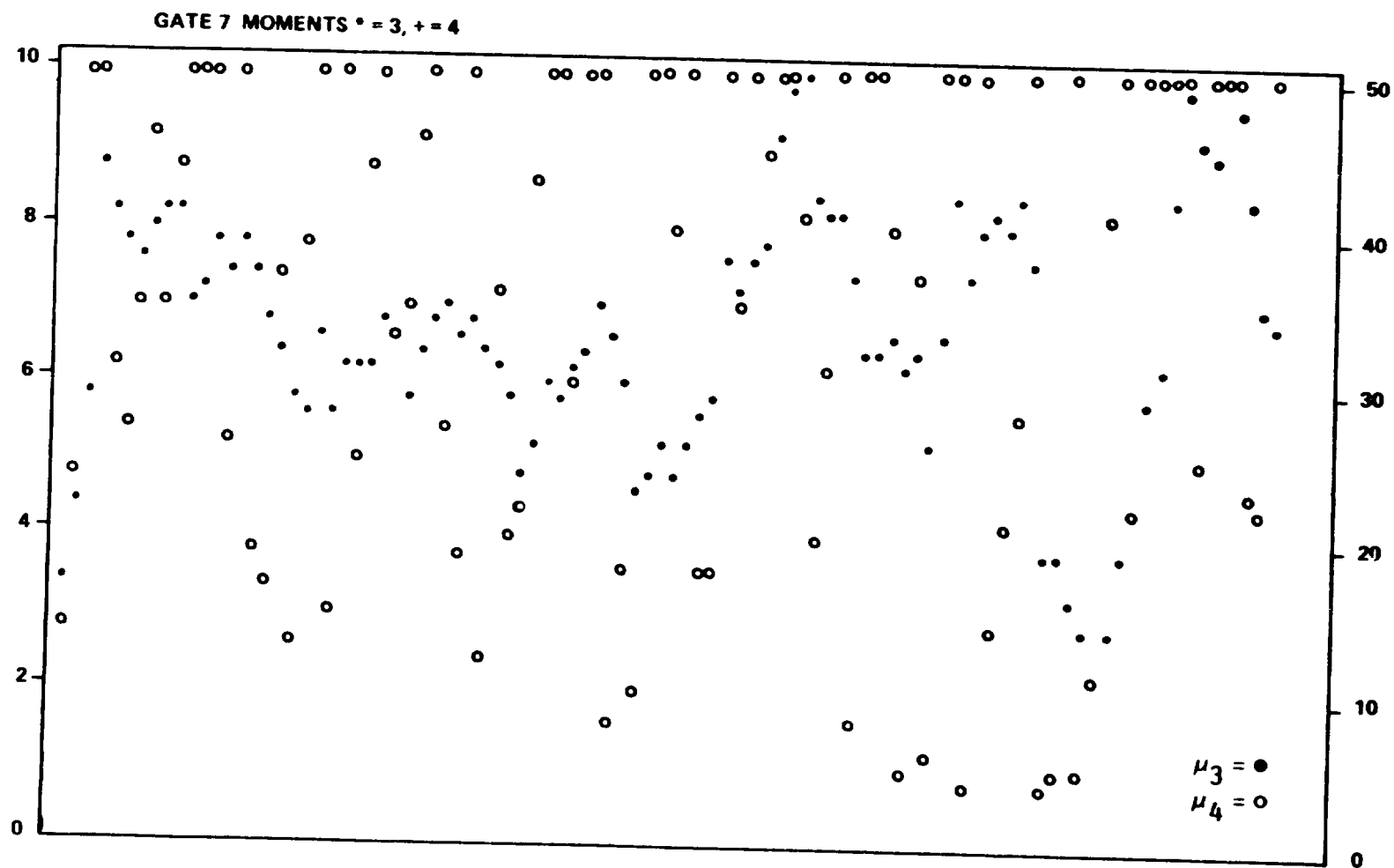


Figure 12. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 7

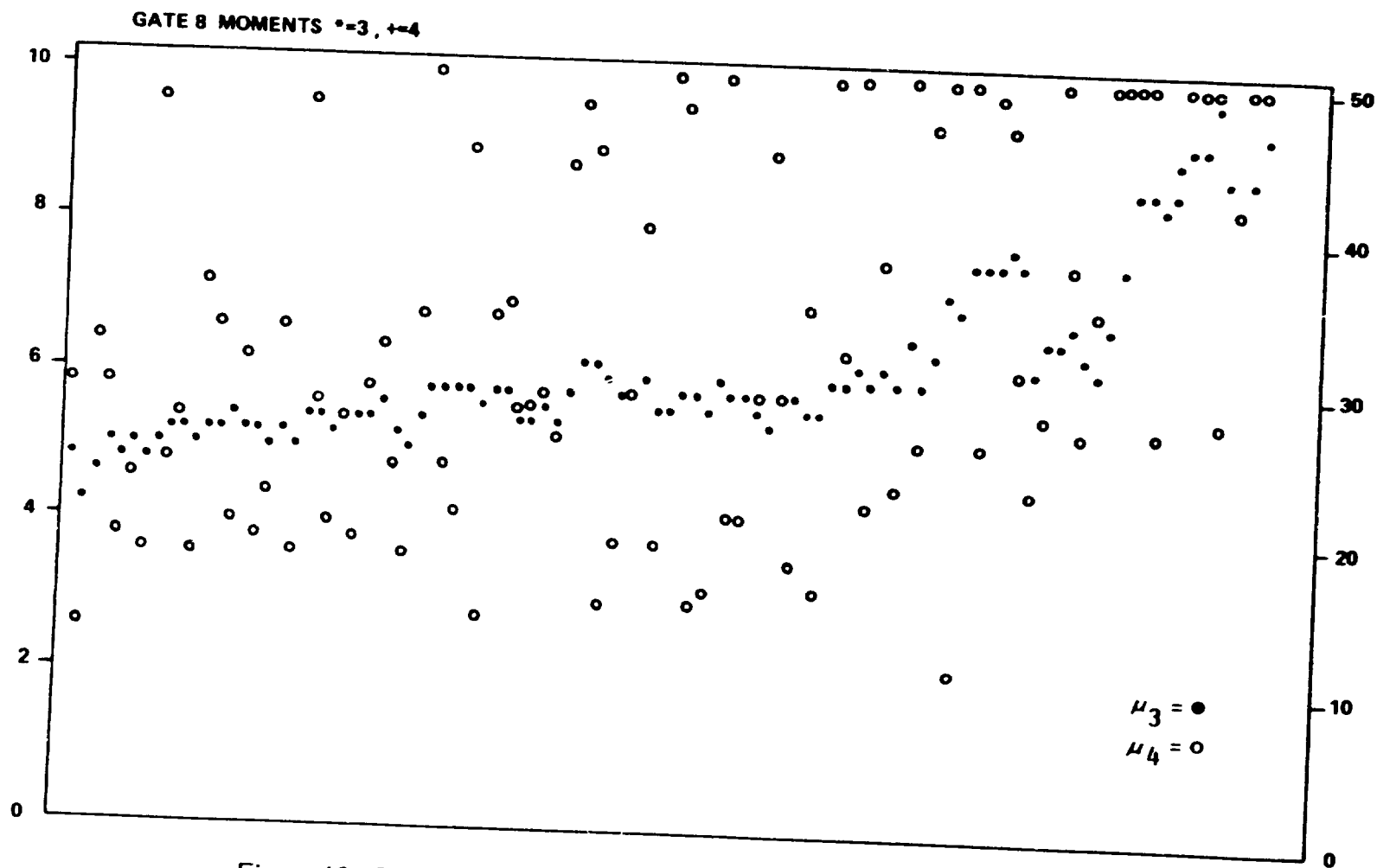


Figure 13. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 8

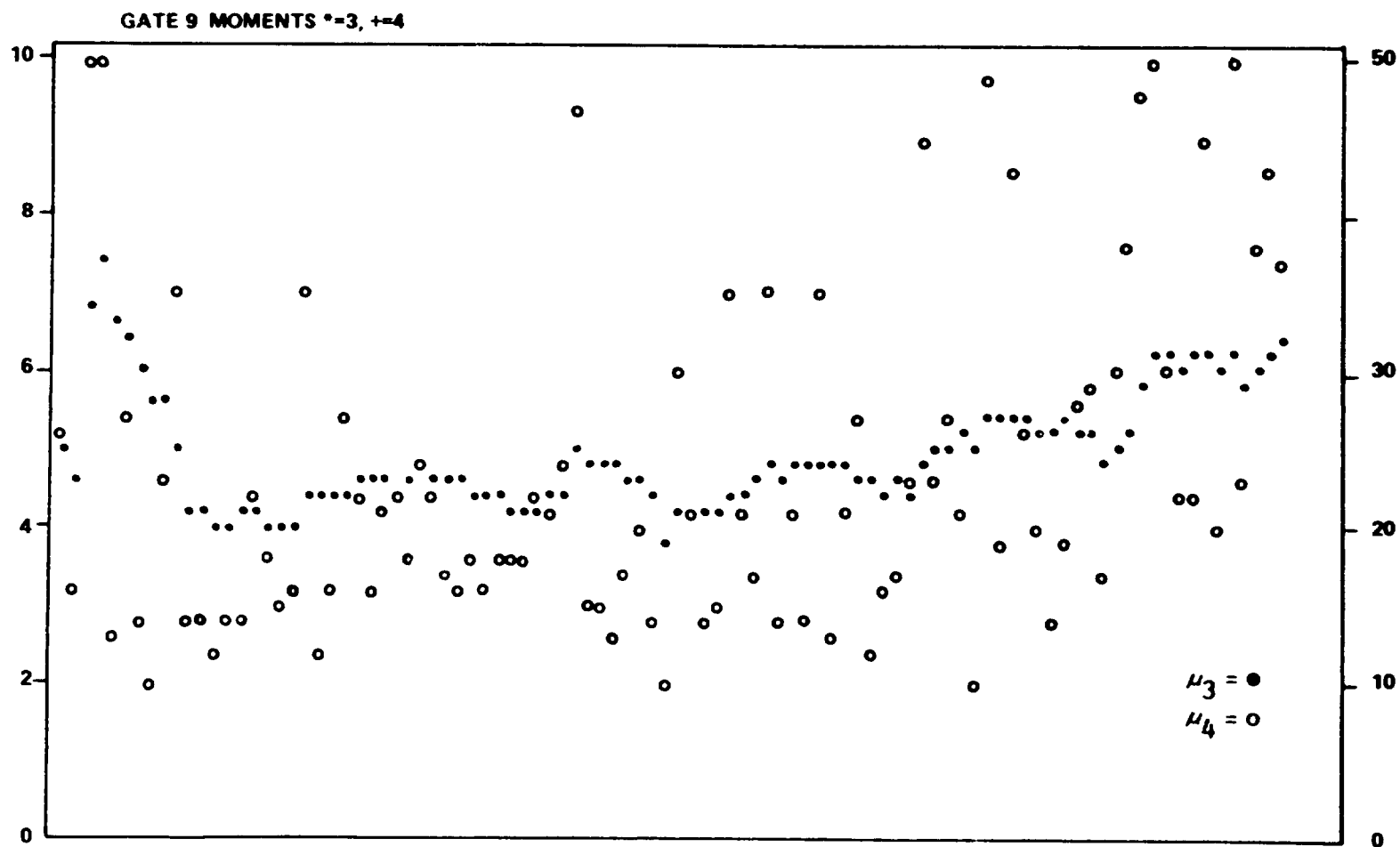


Figure 14. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 9

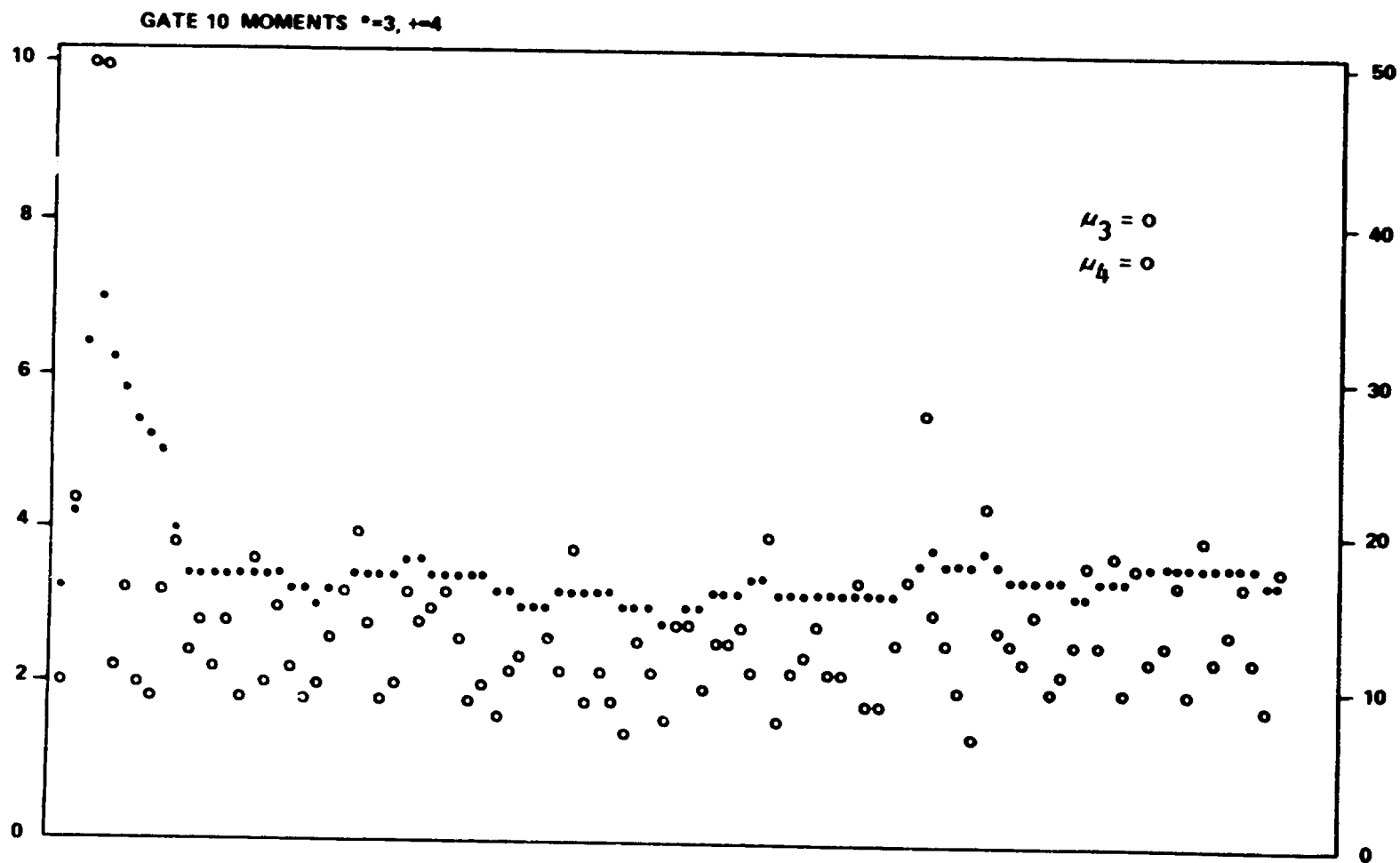


Figure 15. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 10

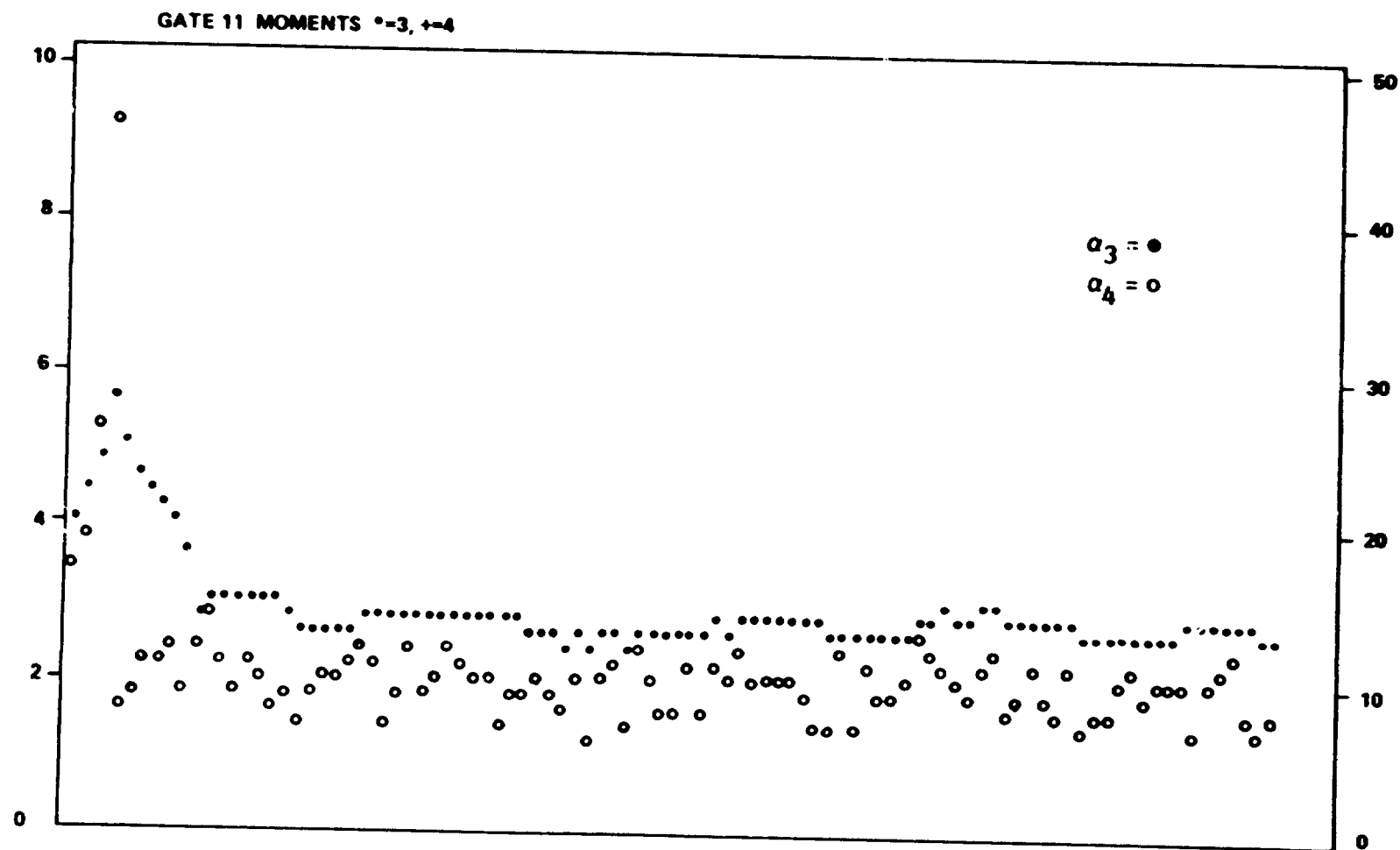


Figure 16. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 11

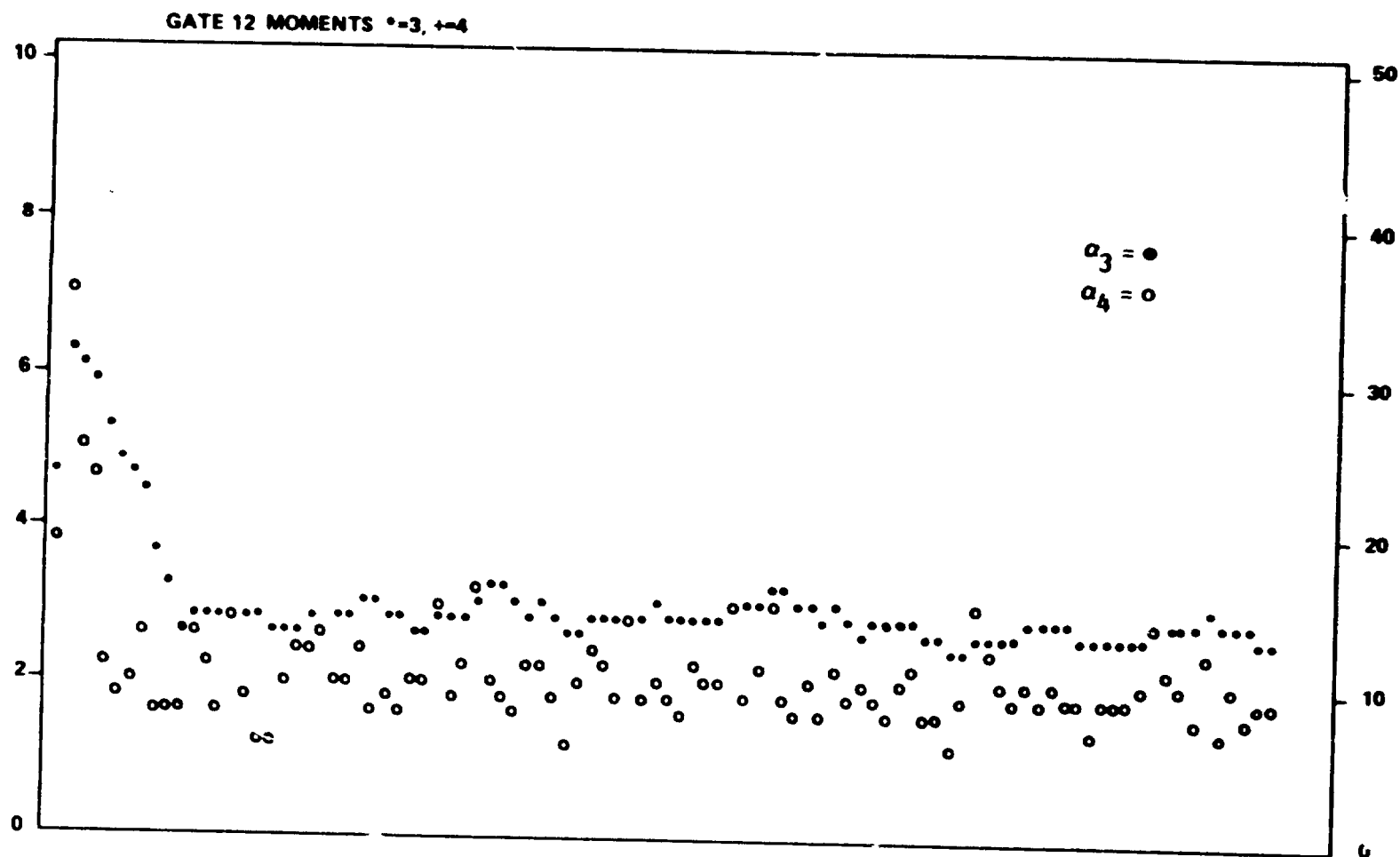


Figure 17. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 12

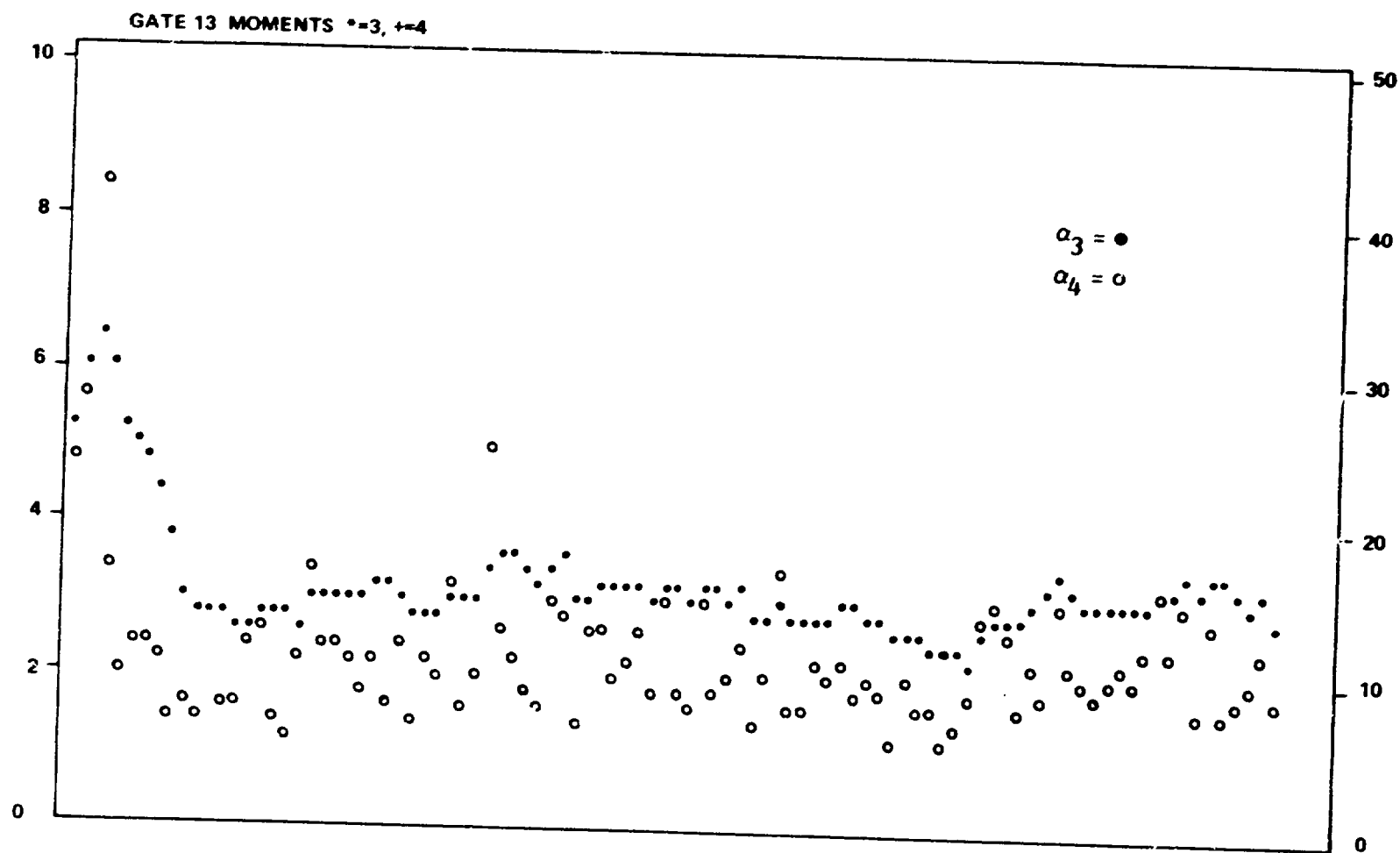


Figure 18. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 13

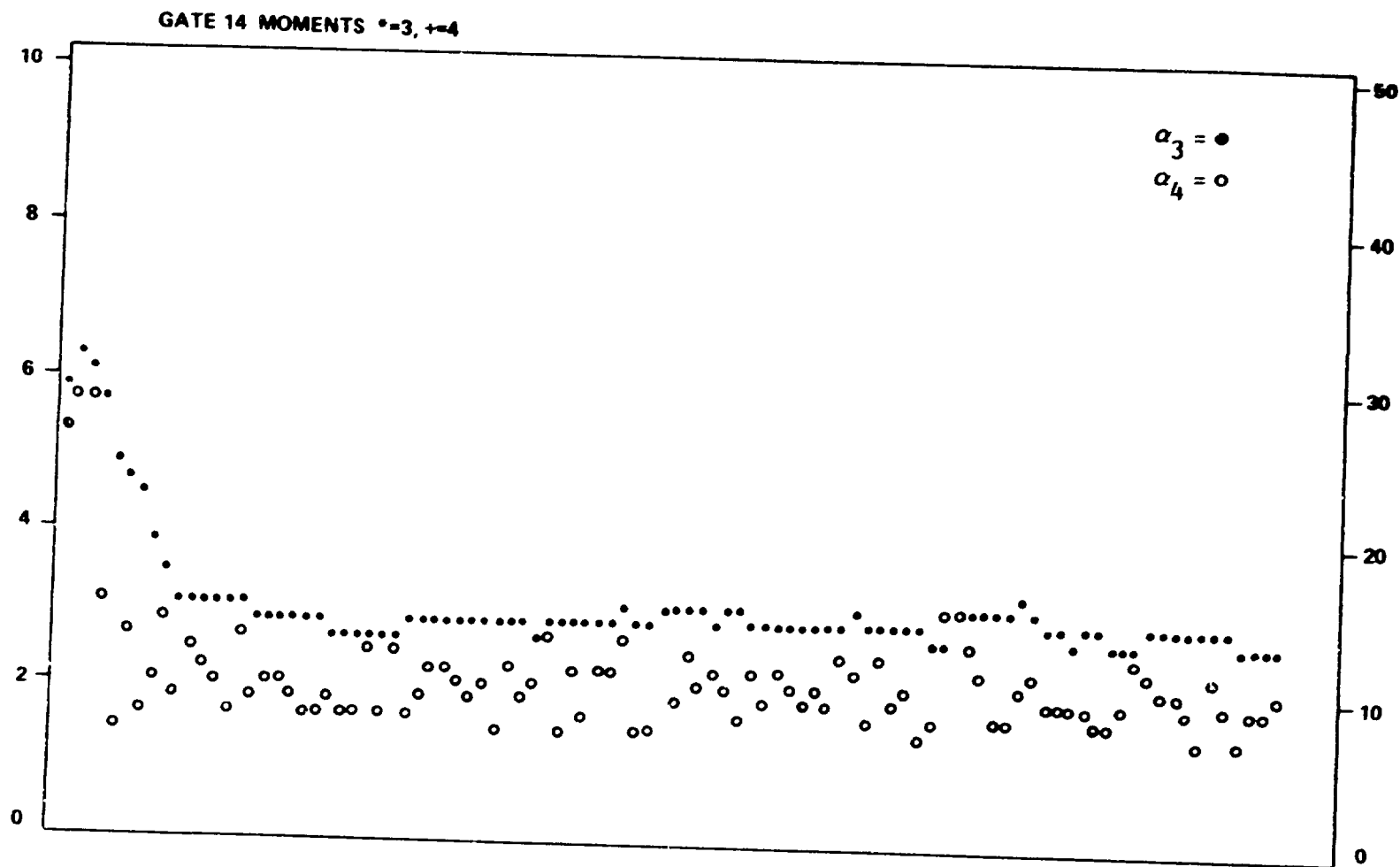


Figure 19. Seven Frame Moving Average Skewness and Kurtosis Coefficients,
Gate 14

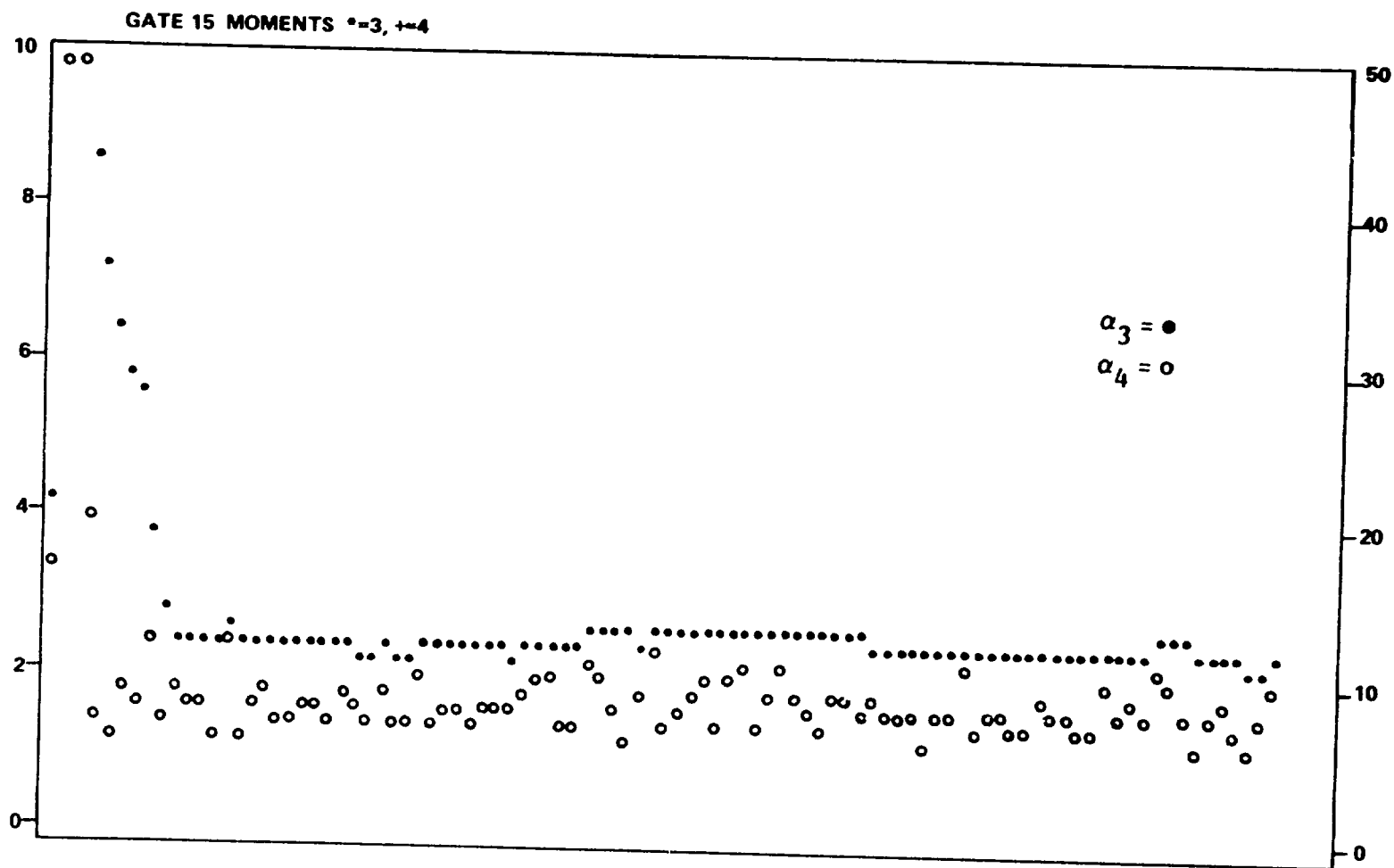


Figure 20. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 15

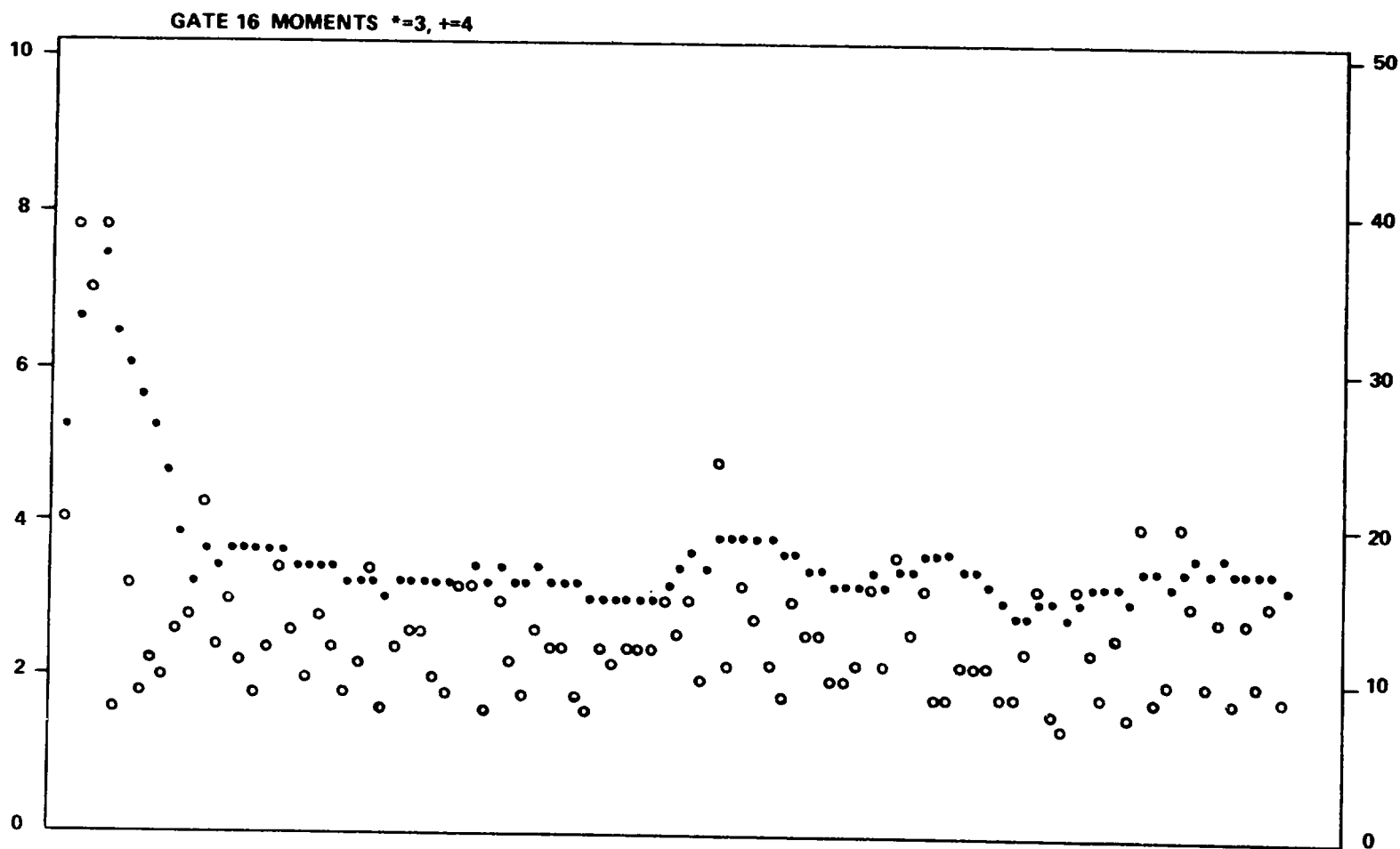


Figure 21. Seven Frame Moving Average Skewness and Kurtosis Coefficients, Gate 16.

5.0 PERCENTILE ANALYSIS

A data set was received for which there is sea state data from buoys nearly simultaneous with the GEOS-3 altimeter data. For analysis the frame of data taken nearest the buoy geographically and in time was chosen. In this data the $H_{1/3}$ values range from 0 to 3 meters. This is the range of sea state values which are the most difficult to obtain by techniques based on the slope of the leading edge of the average return waveform. [1], [2] and [3] An analysis of the third and fourth moments as before showed that there was little predictive capability in these quantities for this range of sea states.

Another method of looking for small changes in probability density functions is to examine the percentiles of the density function. In this case for a given sample and hold gate, these would be the voltage level for which x% of the values are below. Visual inspection of the 75th percentile and 90th percentile for gate 11 seemed to correlate well with the $H_{1/3}$ values. Therefore these values were computed for all gates in the frames of interest in this data set. Table 2 gives a tabulation of the 75th and 90th percentiles for gates 9 to 16 with the corresponding sea state estimates from the buoy data. In Table 2 the column called x_1 is the 75th percentile for Gate 9, x_2 is the 90th percentile for Gate 9 and similarly for the other gates in the tabulation. A multiple regression analysis was performed and it was found that by far the 75th percentile of Gate 11 is the best prediction of sea state having a correlation coefficient of .79. Adding the percentiles for gates 9 thru 16 the correlation increases to .89 but the only statistically significant predictor is the 75th percentile of Gate 11.

REV. NO.	GATE 9		GATE 10		GATE 11		GATE 12		GATE 13		GATE 14		GATE 15		GATE 16		BOUY
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	$H_{1/3}$
7753	22	46	54	94	86	134	110	174	118	198	126	190	118	182	110	182	3.3
9253	30	54	70	94	78	142	110	158	118	174	102	174	102	174	118	182	3.2
4525	30	62	62	102	78	134	102	142	110	166	118	174	118	174	118	182	3.0
8422	30	62	62	94	78	142	118	174	126	206	118	190	118	174	110	182	2.9
7569	22	54	62	102	86	142	110	158	110	158	118	166	110	166	110	166	2.5
6026	22	38	62	102	78	126	102	150	102	174	110	158	110	166	102	166	2.5
5116	30	62	70	118	94	158	110	158	110	174	110	174	110	166	110	182	2.5
8606	22	46	62	86	78	134	112	174	126	190	110	174	126	198	118	182	1.9
7967	22	54	54	102	86	134	110	174	118	190	126	190	118	182	118	182	1.9
8279	22	62	62	86	86	150	118	174	134	174	118	182	126	182	126	198	1.9
6367	22	46	62	102	86	142	110	166	126	190	126	190	134	190	134	190	1.8
7021	22	54	70	110	94	158	118	174	134	182	118	190	126	190	126	182	1.8
6515	30	46	54	102	86	134	102	174	110	182	110	174	110	158	110	166	1.7
8948	22	54	62	110	86	134	102	150	110	174	118	190	110	182	110	182	1.6
7896	22	46	62	110	86	150	102	166	110	174	110	174	118	182	102	182	1.5
10439	22	62	70	102	94	166	126	198	126	198	134	206	126	206	142	206	1.1
4917	30	54	62	110	94	150	102	166	118	182	118	182	110	174	118	174	1.3
3382	22	38	70	102	102	166	126	190	126	190	126	190	126	198	118	182	1.2
6879	30	54	70	110	86	150	102	150	110	158	118	174	110	182	110	174	1.1
6956	30	70	62	94	94	142	110	174	118	174	134	198	126	190	110	174	1.0
7078	22	46	62	110	102	166	110	198	126	174	118	198	110	174	110	174	0.8
6629	22	38	70	102	94	150	110	174	126	198	118	174	118	166	118	182	0.7
4590	22	38	62	110	102	134	110	182	110	214	110	182	110	174	110	174	0.7
5443	22	54	70	110	102	166	126	182	134	190	126	198	126	206	126	190	0.5
6552	22	46	70	110	110	166	134	214	150	230	142	198	134	206	134	190	0.5

TABLE 2. TABULATION OF THE 75th AND 90th PERCENTILES
IN MILLIVOLTS FOR GATES 9 TO 16 WITH SEA STATE.

6.0 SUMMARY AND CONCLUSIONS

After extensive examination of a large number of statistical characteristics of the GEOS-3 altimeter waveforms it was found that the best sea predictor for $H_{1/3}$ in the range of 0 to 3 meters was the 75th percentile of gate 11. This is significant since this is the range of sea states which is most difficult to obtain from an analysis of the slope of the leading edge of the average return waveform. It is possible that percentiles of other gates might be found for estimation of sea states greater than 3 meters.

7.0 ACKNOWLEDGEMENTS

The authors would like to thank H.R. Stanley, J.T. McGoogan and E. Walsh for many stimulating discussions during this study.

8.0 REFERENCES

- [1] Miller, L.S. and Priester, R.W., "An Investigation of the Observability of Ocean-Surface Parameters Using GEOS-3 Backscatter Data," NASA Contractor Report 156846, Wallops Flight Center, Wallops Island, Virginia, 23337, October 1978.

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